H I L G A R D I A

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VIRUS DISEASES OF APPLE[1]

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THREE VIRUS DISEASES of apple have been recognized in California orchards for a number of years. These are mosaic (Thomas, 1937),[3] flat limb (Thomas, 1942) and the disease or group of diseases variously called false sting (Hockey, 1941, 1943), green crinkle (Atkinson and Robbins, 1951), star cracking (Jenkins and Storey, 1955) and perhaps other names.

APPLE MOSAIC

Mosaic has been seen in a considerable number of apple orchards in the state since 1932, but, with one exception, never in more than 3 or 4 trees in any one orchard (Thomas, 1937). In the exceptional orchard at Paradise in Butte County, a block of the Ranier variety contained 24 infected trees out of 70 in 1935; in 1954, 24 trees were again found. Adjacent Delicious and Golden Delicious trees were unaffected. Natural spread therefore seemed to be slight or nonexistent.

A single unexplained infection appeared in an apple seedling in a plot at Berkeley, growing within 3 or 4 feet of a known infected tree. A possible explanation for this comes from New Zealand (Hunter, Chamberlain, and Atkinson, 1958). In an area where natural spread was previously unknown, infected cions were grafted into alternate seedlings in a nursery row of 10-inch spacing. Within a few months symptoms appeared on 5 of 160 ungrafted seedlings. Natural root grafts were offered in explanation but vectors of limited movement cannot be excluded.

There is evidence of natural spread in some areas where trees usually stand widely spaced, where root grafts are rarely encountered and where, no doubt, vectors differ in kind or number (Blodgett, 1938).

Typically the symptoms in cultivated apple, *Pyrus malus* L., in the California area are mild to severe mottling of the early leaves of the growth cycle. A more distinctive symptom, however, consists of broad chlorotic bands along the larger veins (fig. 1). Rarely, a broad yellow to white band crosses the veins, in some cases separating green from mottled zones in the leaf blade (fig. 2). In warm sunny districts, the larger chlorotic spots often die from sunburn.

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[3] See "Literature Cited" for citations referred to in the text by author and date.

Apples of the same variety seem to produce the same kind of symptoms in varying degrees of severity, although cultures (or strains) vary in other ways (Yarwood, 1955; Gilmer, 1958).

Mosaic from the Paradise orchard mentioned above was transmitted by grafting to *Cotoneaster harroviana,* loquat, rose, *Sorbus pallescens* (Thomas, 1937) and more recently to the crab apple, *Pyrus transitoria* var. *toringoides* Bailey. Kegler (1959) reports infection in *Malus ioensis* Bailey and *M. lancifolia.* Kirkpatrick (1955) reported the production of mild but definite chlorotic lines in leaves of peach seedlings as a result of bud and leaf patch inoculation from affected apple; he also reported the recovery of mosaic virus in apple from such peaches. Gilmer (1956) and Posnette and Ellenberger (1957) have produced mosaic in apple by inoculation from plums affected by line pattern.

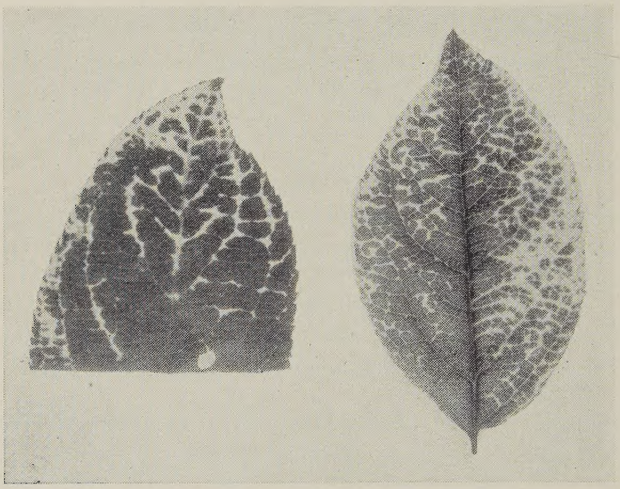

Fig. 1. Chlorotic bands along veins, a characteristic symptom of apple mosaic.

One rose mosaic virus found in central California (Thomas and Massey, 1939) and several peach ring spot collections (Cochran, 1950) produced mottling in apple leaves, but seemingly the mottling differed from that seen in apple orchards in the state.

Two mosaics of crab apples collected locally, one in the kaido crab (*Pyrus micromalus* Bailey) (Thomas, 1937) and another in a different species tentatively identified by Dr. Donald Wyman as *Pyrus floribunda* Kirchn., appear to be clearly distinct from those in *P. malus* L. and from each other. Both failed to infect *P. malus.*

Other virus diseases, distinct from typical mosaic, which affect apple leaves are that found by Mulder (1955) associated with rough skin of fruit, leaf pucker (Welsh and Keane 1957, 1959*b*) and chlorotic leaf spot (Cation and Carlson, 1960), and perhaps some of those found in eastern Europe (Christoff, 1958).

Despite the obvious loss of functional leaf area, apple mosaic does not seem to greatly diminish the over-all vigor of the tree in California, and

since it does not seem to spread appreciably in the orchard, it can hardly be regarded as a major problem in this area. Strains capable of substantial damage to the tree have been found, however, in other countries (Posnette and Cropley, 1956; Mallach, 1957).

Heat has been used to inactivate apple-mosaic virus in infected tissues (Posnette and Cropley, 1956) and to enhance infection (for example, 100 seconds at 45° C after inoculation) (Yarwood, 1958).

Of 169 trees grown from seed of an infected tree, none developed mosaic symptoms.

Fig. 2. Apple mosaic in which chlorotic band separates green from mottled areas and crosses larger veins.

One apple-mosaic virus (from Tulare County) was probably the first fruit-tree virus to be transmitted mechanically from trees to herbaceous plants and back to the same tree species (Yarwood, 1955). This success initiated a substantial breakthrough by Yarwood and others in methods of inoculation and of determining suscept range and other characteristics of a number of viruses in woody plants (Yarwood, 1953, 1957*a*, *b*, 1958; Gilmer, 1958).

FLAT LIMB

The name flat limb (Eastham, 1939;[4] Thomas, 1942), apparently first applied by growers, seems appropriate for the disease considered here, since it refers to the appearance of numerous more or less flattened areas on affected trunks and branches (fig. 3). The names furede grene (furrowed branches), used in Denmark (Kristensen, 1950, 1955, 1956), and Rillenkrankheit, used in Switzerland (Blumer, 1956*a*), are also descriptive, referring to longitudinal furrows or grooves in trunks and branches, which may

[4] Reporting work of H. R. McLarty.

Fig. 3. Flat limb of Gravenstein showing eccentric growth and flattened areas.

be the predominant symptom (fig. 4). "Twist" is used in Australia (Broadfoot, 1956) and "gnarling" in New Zealand (McKenzie, 1953) because of the common occurrence of spiraling ridges of overgrowth associated with the flattened or retarded areas. "Plastomania" is used in Italy, perhaps with as much reason as any name (Biraghi, 1942). Heald (1920) probably included flat limb under "spiralism."

The symptoms above occur primarily on older parts of the tree and are often accentuated by obstructions to the free flow of sap, such as those created by the graft unions of topworked trees. The erroneous but persistent impression that the disease is caused by graft incompatibility (McAlpine, 1911–1912; Hockey, 1943; Broadfoot, 1956) is no doubt related to this fact. Hockey (1957) later recognized the infectious nature of the disease.

Occasionally, and usually in more distal parts of the tree, fusiform or spindle-shaped swellings appear (fig. 5) (Blumer, 1956*a*) without any obvious relation to obstructions in sap flow. Enlargement at the bases of lateral branches (fig. 6) also seems to be a symptom. Adjacent to the flat areas and bottoms of the furrows, where growth of wood is slight, there are often ridges in which wood growth appears to be near and even in excess of

Fig. 4. Flat limb of Gravenstein showing chiefly furrowing of trunk and branches.

normal (fig. 3). The bark is of about the same thickness on the ridged and in the depressed areas but seems to be considerably disorganized in the latter (Biraghi, 1942; Blumer, 1956*a*), where there is no longer a sharply defined cambium line and phloem seems to be displaced to a considerable extent by ray cells in the phloem zone. In areas of continuing wood growth, a new cambial line may advance leaving behind a former cambial line with xylem on both sides of it (fig. 7), possibly indicating the level at which the disease began to affect this part of the tree.

There is no general necrosis of bark or wood in early stages, though localized internal necrosis has been noted (Blumer, 1956*a*). In later stages when foliage has become sparse, the bark of affected trees often becomes sunburned and is frequently invaded in these burned areas by such fungi as *Polystictus versicolor* Fr. and *Schizophyllum commune* Fr.

The over-all effect on the trees is a relatively slow deterioration under otherwise favorable orchard conditions. In one orchard containing 60 affected Gravenstein trees, the first were not removed until they were about twenty-three years old, and the evidence suggests that these trees had been infected when they were planted.

Varieties and species affected. Flat-limb symptoms have been seen in California only on Gravenstein among apple varieties. Eleven other varieties[5]

[5] Baldwin, Bellflower, "Greening," Golden Delicious, Mammoth Black Twig, McIntosh, Red Astrachan, Rome, and Smith's Cider.

Fig. 5. Fusiform swelling occasionally seen in flat limb of Gravenstein.

which were exposed to the disease by grafting and which did not develop symptoms have been seen by the writer or reported by growers. But it has been shown here and elsewhere (Kristensen, 1956) that apples other than Gravenstein may carry the virus without symptoms. In Canada and Europe, symptoms of the disease have been reported on the apple varieties Abbondanza, Bodil Neergaard, Dronning Louise, Fillipa, Golden Pearmain, Gravenstein, Höve Pippin, Ildrod Pigeon, James Grieve, Labygard, Lord Lambourne, Lord Suffield, Ontario, Rambour franco, Schneider, Signe Tillisch, Tobiäsler and Wagener (Blumer, 1956*a*, *b*; Hockey, 1943; Kristensen, 1950, 1955, 1956; Luckwill, 1955; Ramsfjell, 1950).

Fig. 6. Flattened areas and swollen base of side branch on Gravenstein at right. Roughening of bark and thickening of stem of *Pyracantha* at left.

Symptoms resembling those of flat limb have been reported on pear (Biraghi, 1942).

Thickening of stems and roughening of the bark of *Pyracantha gibbsii yunnanensis* (fig. 6) has been produced by graft inoculation from infected Gravenstein apple (Thomas, 1942). Similar inoculations failed to produce symptoms on *Chaenomeles lagenaria* Koidzumi, *Citrus paradisi* Macf., *Cotoneaster franchetii* Bois, *Crataegus douglasii* Lindl., *Cydonia oblonga* Mill., *Photinia arbutifolia* Lindl. and *Pyrus communis* Linn.

Symptoms similar to those of flat limb are sometimes seen on *Photinia arbutifolia,* and on pear heavily infested by the Italian pear scale *Epidiaspis piricola* (Del Guer.) and on citrus infected by some strains of the psorosis virus (Wallace, 1957).

When healthy Gravenstein cions were grafted on affected trees, the short-

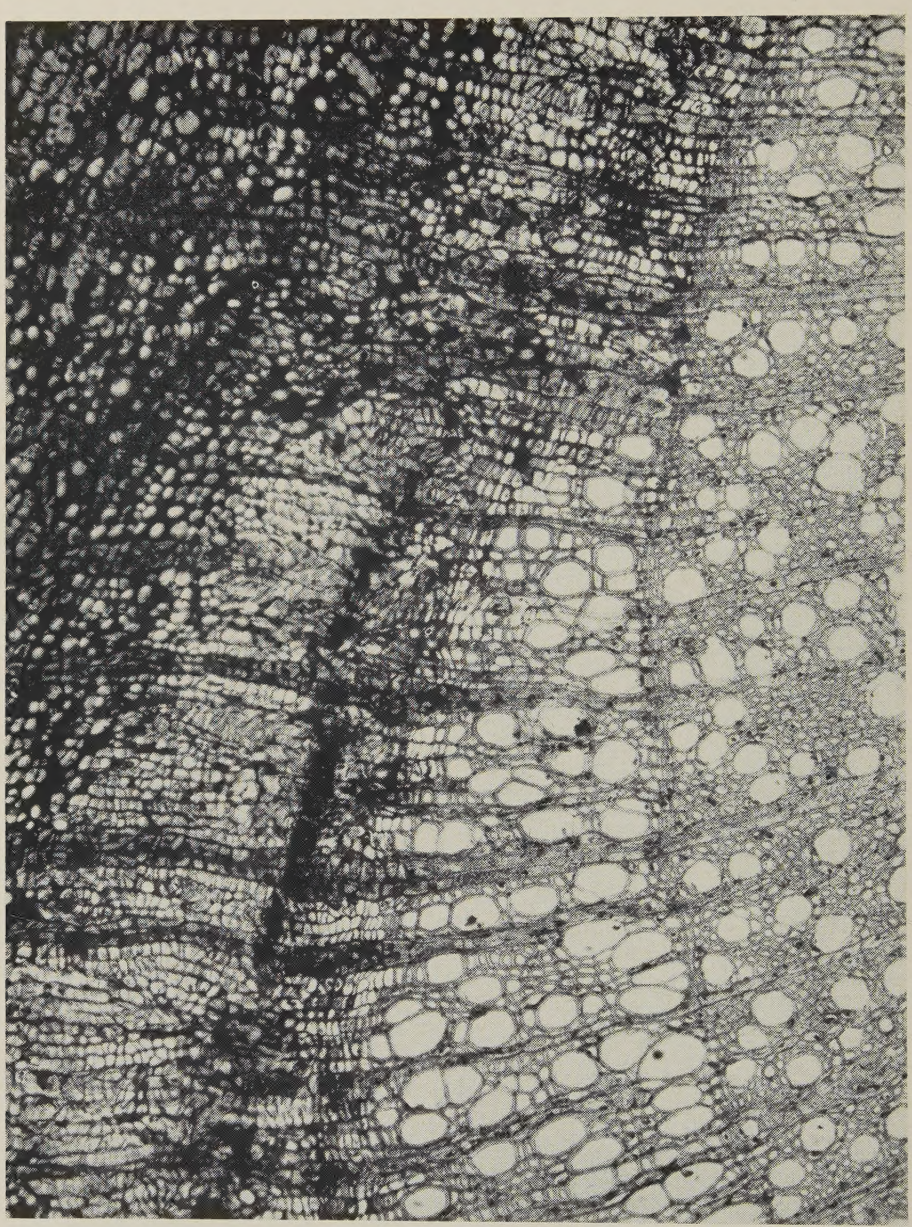

Fig. 7. Transverse section at junction of retarded (at top) and proliferating (at bottom) portions of apple stem affected by flat limb. Two cambial lines are seen at bottom, the older at right and the current one at left. × 134. Section and photo by Dr. Henry Schneider.

est incubation time observed by the writer was 15 to 18 months. Slow-growing trees may require fifteen years or more to develop pronounced symptoms. Kristensen (1955, 1956), however, has reported intervals of 8 months to five years. In one instance *Pyracantha* began to show bark cracking slightly more than 6 months after inoculation at Berkeley.

Successive examinations of several mature orchards in 1933 and 1944 revealed no new infections and no great change in trees infected at the beginning of this period. Affected and healthy Gravenstein trees have stood side by side in field plots at Berkeley and Albany for more than twenty years without any sign of natural spread.

The disease is gradually disappearing in the Gravenstein orchards of California because of the removal of affected trees and the increasing awareness of the disease among growers and nurserymen since 1917.[6]

Fig. 8. Green crinkle in Bellflower fruit collected near Soquel, Santa Cruz County, July 12, 1944.

GREEN CRINKLE

Green crinkle (Atkinson and Robbins, 1951; Atkinson, 1956) is a descriptive name for a disease or complex also called "false sting" (Hockey, 1941, 1943) and probably related to star cracking of apple fruits (H. Fischer, 1955; Jenkins and Storey, 1955; Posnette and Cropley, 1959; Reeves and Lindner, 1959; Blodgett and Aichele, 1961). The disease called "rough skin" in Europe (Bomeke, 1954; Mulder, 1955; van Katwijk, 1955) may well be related, and possibly also the scar skin of Missouri (Millikan and Martin, 1956; Millikan and Guengerich, 1960; Posnette and Millikan, 1958). A rough skin of apple which is graft-transmissible has also been reported from Manchuria (Otsuka, 1938).

The green-crinkle symptom (figs. 8–11) was discovered in the Bellflower variety in 1942 by Matt Mello, Agricultural Commissioner of Santa Cruz County. It has since been seen in Delicious, Gravenstein (fig. 9) and "Red Pearmain" in the same county. Severe "star cracking" (fig. 10) was also

[6] Correspondence of the late Ralph E. Smith.

Fig. 9. Green crinkle in Gravenstein near maturity of that variety. August 9, 1945.

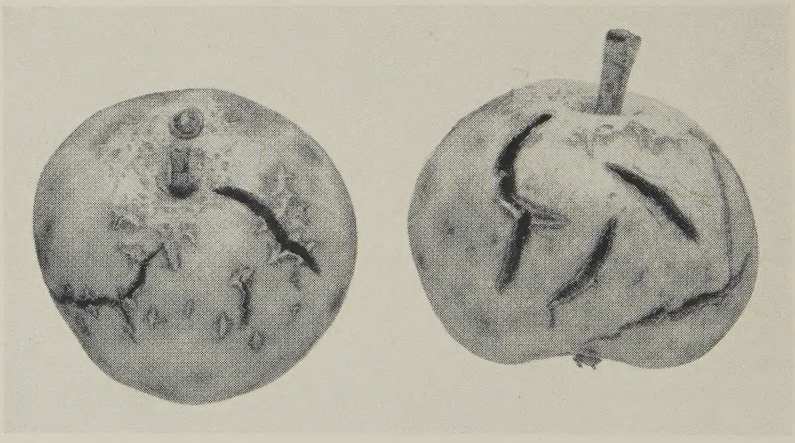

Fig 10. Yellow Newtown fruit affected by a star cracking not yet transmitted.

found in Santa Cruz County in a large branch of a mature Yellow Newtown (Newtown Pippin) tree by Edward Koch, Farm Advisor. Rough skin and cracking of Cox's Orange fruits have been seen in a garden in Alameda County.

Symptoms. Irregularly shaped depressions which are often elongate appear in the fruit surface, sometimes by the end of June. As the fruit develops a mature red or yellow color, the bottom of the depression remains green. Still later these depressed areas become superficially corky and cracked

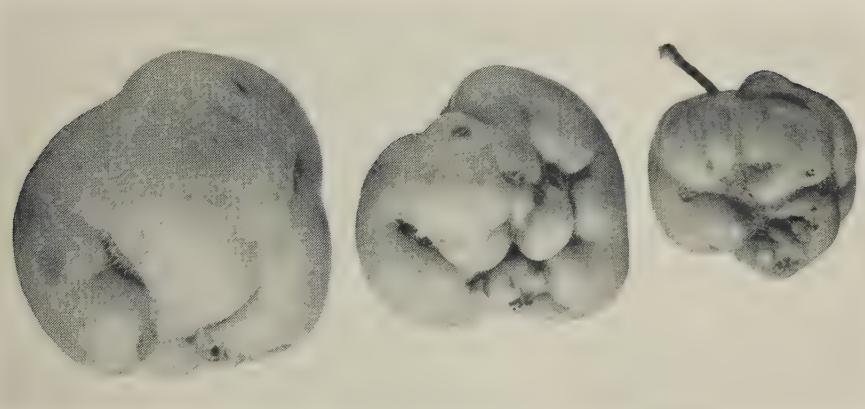

Fig. 11. Green crinkle in Bellflower from the same orchard as shown in fig. 8 but collected in September 1954.

Fig. 12. Green crinkle of Bellflower from same source as shown in figs. 8 and 11 but collected in November 1942. Note resemblance to star cracking.

(figs. 9, 11, 12). Severely affected fruits are considerably reduced in size. There is little or no necrosis beneath the depressions, which fact assists in separating this disease from the "crinkle" (Atkinson, 1947; Brooks and Fisher, 1926; Smith and Smith, 1911) now attributed to direct heat injury, and also from bitter pit (Smock, 1941) and cork (boron deficiency, fig. 13) (Burrell, 1940).

It has been noted in New Zealand (Atkinson, 1956) that green-crinkle symptoms may be confined to a single branch of a tree for as long as ten years before they appear in other parts of the same tree.

The star cracking of Yellow Newtown (fig. 10) was seen in one branch of a single large tree which is said to have been so affected for several years.

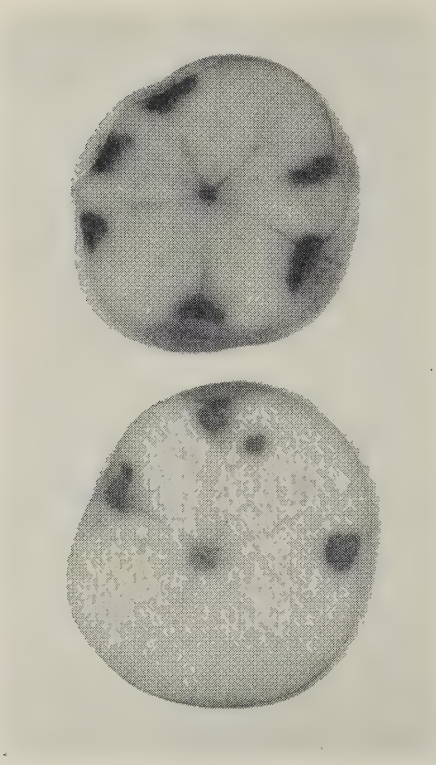

Fig. 13. Symptoms of boron deficiency (cork) in apple.

Cions from this branch grafted to small trees did not transmit the symptoms to the same variety in three seasons. But inoculation from Bellflower which bore green-crinkle fruit did eventually produce mild cracking on a few fruits of Newtown, and severe rough skin and cracking on seedling fruits on the same tree (fig. 14).

The rough skin of Cox's Orange, mentioned above, sometimes centered mainly around the pedicel but occasionally appeared elsewhere accompanied by cracking. These symptoms persisted in cions moved to Berkeley and apparently were transmitted to Golden Delicious fruits in June 1958 by grafts made in February 1957.

The infected trees in California are not noticeably affected in leaf, bark or general growth. Bark blisters and dieback, however, have been associated with star cracking in England (Jenkins and Storey, 1955), and vein clearing has been seen in Holland on trees affected by rough skin (Mulder, 1955).

Varieties affected. Green crinkle, false sting, and star cracking have been reported in more than twenty varieties including Baldwin, Beauty of Boskoop, Bellflower, Ben Davis, Blenheim Orange Pippin, Bramley, Cox's Orange, Delicious, Dunn's, Fuhr, Glocken, Golden Delicious, Granny Smith, Gravenstein, Lord Wolseley, McIntosh, Northern Spy, Ontario, "Red Pearmain," Statesman, Sweet Alford and Tompkins King (Atkinson and Rob-

bins, 1951; Posnette and Cropley, 1959; Hockey, 1943; H. Fischer, 1955; Mulder, 1955; Blumer, 1956*b*; van Katwijk, 1955, 1956).

Inoculations. Because trees long infected with the disease may produce no symptoms in a given year, no meaningful incubation time has been established here. A period of three to five years was noted in Nova Scotia (Hockey, 1941). From 1942 to 1953, eleven varieties were exposed to the green-crinkle virus by grafting onto orchard trees inoculated by affected Bellflower cions. No certain symptoms were seen on any variety up to 1951. Even when the seedling fruits of one such tree were severely pitted and cracked (fig. 14), Bellflower fruits were only slightly affected, and several other varieties such

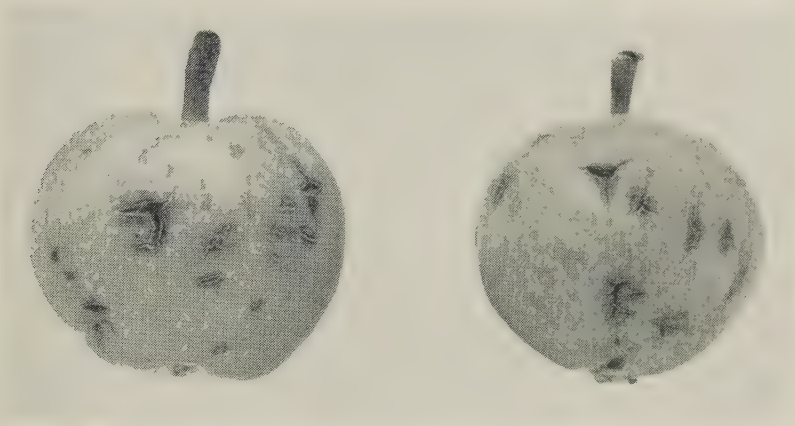

Fig. 14. Seedling apple fruit of tree inoculated from the Bellflower source shown in figs. 8, 11, and 12.

as Delicious, Golden Delicious, Melba, Red Jonathan, Starking, White Winter Pearmain and Winter Banana displayed no symptoms.

These tests can hardly be considered to be adequate to determine the tolerance of a variety.

Spread in orchard. While the appearance of symptoms of green crinkle on one branch of a very old Bellflower tree suggests an occasional natural infection, successive mapping of 85 Bellflower trees in one orchard indicated 27 infected trees in 1944 and 26 in 1953. Neighboring Delicious and Yellow Newtown trees had no symptoms. It must be concluded that natural spread, if any, is slight. Apparently, natural spread is also slight or nonexistent in Nova Scotia (Hockey, 1943).

Only one orchard has been seen in which a considerable number of trees were affected (27 per cent of 116 Bellflower trees), and in most years many affected trees fail to produce symptoms. Since the disease is severe in colder areas (Hockey, 1943), it may be suggested that warmer weather tends to suppress symptoms. In two years (1944 and 1953) in which symptoms were relatively severe at Soquel (fig. 8), mean temperatures at nearby Santa Cruz were below normal from February to July inclusive in every month except one—March 1944.

VIRUS DISEASES OF APPLE NOT YET RECOGNIZED IN CALIFORNIA

Stem pitting. Stem pitting of Virginia Crab (Guengerich and Millikan, 1956) and the latent lethal of Spy 227 (Gardner, Marth and Magness, 1946; Weeks, 1948) have been associated closely with these cold-hardy body (or intermediate) stocks until recently, but it is now apparent that the pitting virus may affect a considerable number of other body stocks and also some fruiting varieties including Delicious and Golden Delicious (Keane and Welsh, 1959; Mink and Shay, 1959*b;* Welsh and Keane, 1959*a*).

It is suggested that the stem-pitting and lethal effect in Spy 227 are caused by the same virus (Guengerich and Millikan, 1959). A chlorotic leaf spot distinct from mosaic has been associated, but not invariably, with stem pitting in Indiana and Michigan (Mink and Shay, 1959*a;* Cation and Carlson, 1960). Leaf symptoms have been produced in Missouri in Amelanchier, Crataegus, *Malus floribunda* Sieb. and *M. platycarpa* Rehd. by inoculation with stem-pitting material (Millikan and Guengerich, 1959).

Rubbery wood. Rubbery wood is at least a potential threat to apples in this country. The Lord Lambourne variety, severely affected in Europe, is rare in the United States but Golden Delicious, Jonathan, and other varieties are known to be affected in greater or less degree. Still others, including several clonal rootstocks occasionally introduced into this country, may be symptomless carriers (Posnette and Cropley, 1954; van Katwijk, 1954). Apparently, symptoms have been seen on Golden Delicious and Stayman in Missouri (Posnette and Millikan, 1958). The virus was reported in New York in 1959 (Brase and Gilmer, 1959). The chief symptoms are undue flexibility of branches and softness of wood accompanied by a reduction in growth. The wood of affected branches is shown to be incompletely lignified by staining with phloroglucinol and other materials (Beakbane, Beryl, and Thompson, 1945*a*, *b;* Prentice, 1950; van Katwijk, 1954). The virus was not inactivated in New Zealand by temperatures of 99°F for 40 days (Atkinson, Chamberlain, and Hunter, 1959).

Brooming, proliferation, and rozet. The names, brooming (Ciferri, 1956; Morvan, 1958; Ciferri, Rui and Refatti, 1955), proliferation (Bomeke, 1954; Blumer, 1956*b;* R. Fischer, 1957; Mulder, 1953) and rozet (van Katwijk, 1953; Nataljina, Panjkova, and Sestakova, 1951) have been used for diseases whose main symptoms are precocious growth of lateral buds and/or shortening of internodes. Shape, size and color of leaves and fruitfulness may also be affected. Several workers in Europe have transmitted such symptoms by grafting. Blumer (1956*b*) has pointed out that other agents, such as aphis and mildew may also produce somewhat similar symptoms. At Ithaca, New York, in 1925, the writer collected brooms (fig. 15) which closely resembled some of the recent pictures from Europe. These brooms had been attributed to the leafhopper *Empasca mali* LeBaron (Lathrop, 1918) and were accepted as such at the time. The name rosette has sometimes been used in this country to designate a stunting of shoots, which later was attributed to mineral deficiency (Burrell, 1940).

Ring spot. Ring spot of apple fruits (Atkinson, Chamberlain, and Hunter,

Fig. 15. Proliferation in apple attributed to *Empoasca mali*. Ithaca, New York. 1925.

1954) seems to be similar to the rough-skin diseases but has two or more distinctive features. The superficial russeted spots are often circular in shape and, near harvest time, may be surrounded by a narrow band of smooth dark brown tissue. Sometimes striking concentric rings or partial rings appear on these spotted fruits. Somewhat similar but coarser rings or ring fragments (fig. 16) have been eliminated in New York (Burrell, 1940) and in California by boron applications, but the New Zealand trees mentioned above had not responded to boron after one year. Complete concentric rings (fig. 17) have been seen infrequently in Sonoma County, apparently only on land deficient in boron.

Russet ring and leaf pucker. A ring marking of fruits designated "russet-ring" (Reeves and Cheney, 1959; Welsh and Keane, 1959*b*) is found in British Columbia and Washington State. The area within the ring is often unaffected but affected fruits may be somewhat malformed. A leaf pucker symptom (Welsh and Keane, 1957) is closely associated with the russet ring. Similar fruit and leaf symptoms have been seen in Holland (Mulder, 1955

Fig. 16. Boron deficiency (drought spot) of apple.

and on Golden Delicious fruit in local markets in Berkeley and Walnut Creek, California (fig. 18).

Green ring mottle and dapple apple. Green ring mottle (Palmiter and Parker, 1955; fig. 19) and dapple apple (Barrat, Smith, and Rich, 1959) have caused superficial marking of fruits in New York and New Hampshire but apparently they are distinct from each other.[7] Both have been transmitted by grafting in two or three years. The former affects chiefly the Duchess variety, while the latter has produced symptoms in inoculated Courtland, Delicious, Golden Delicious, and McIntosh (Barrat, Smith, and Rich, 1958).

Chat fruit. The virus disease called "chat fruit" (Luckwill and Crowdy, 1950) in Europe, the chief symptoms of which are reduction in size and red pigment of Lord Lambourne fruit, is not definitely known to be present in this country. It could easily be overlooked, however, since these symptoms can also be produced by inadequate light and nutrition. This disease is believed to be present in Missouri (Posnette and Millikan, 1958) in Delicious and Jonathan.

[7] Correspondence from K. G. Parker.

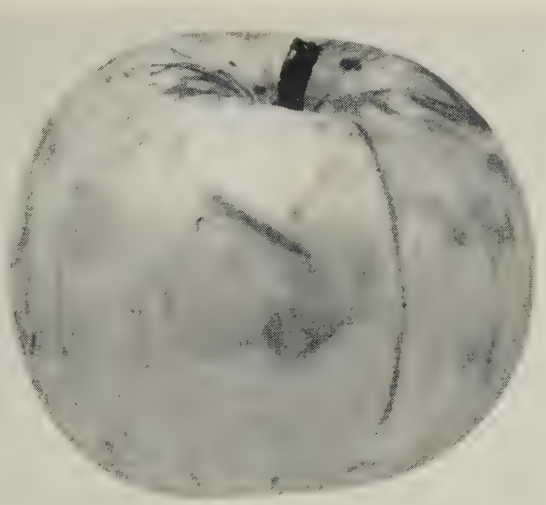

Fig. 17. Gravenstein fruit showing concentric lines. From an orchard near Forestville affected by boron deficiency.

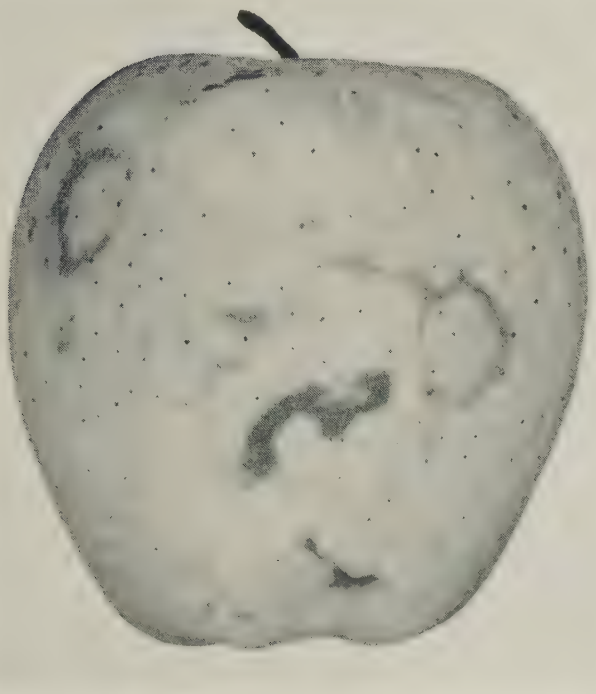

Fig. 18. Russet ring of Golden Delicious.

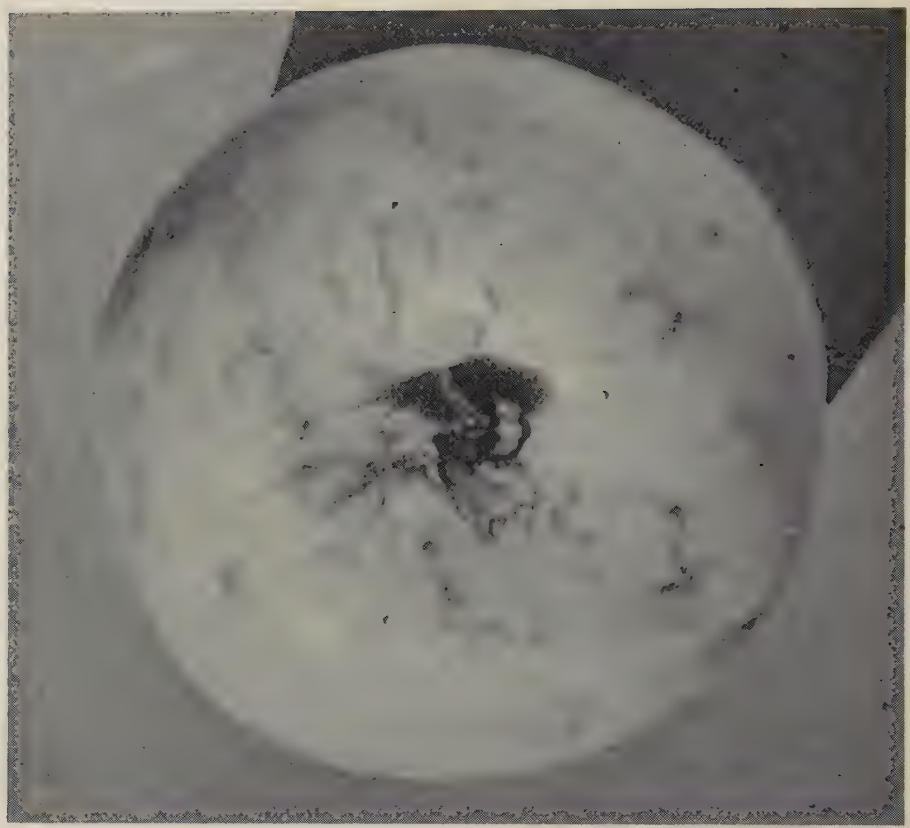

Fig. 19. Green ring mottle of apple in New York. Courtesy of K. G. Parker.

Fig. 20. Sheep nose in Gravenstein. Cause unknown. Collected in September. Normal fruit at right.

Dwarf fruit. A graft-transmissible disease of Jonathan and Hyslop called "dwarf fruit" (Cation, 1960), under observation in Michigan for some years, reduces the size and red[5] pigment of affected Hyslop fruits and in addition causes longitudinal ridges on such fruit. Cation (1961) has presented evidence of a relation between dwarf fruit and the lethal virus of Spy 227.

Sheep nose. In at least one Gravenstein orchard in Sonoma County, some trees bear small fruits with reduced pigment and an elongate or sheep nose shape, somewhat resembling that of Delicious fruits (fig. 20). Fruits of normal appearance are found on the same tree. Adjacent trees appear to be normal throughout. A single attempt to transmit this condition by grafting was not successful after three years, but this test is not considered to be conclusive.

DISCUSSION

No doubt other virus diseases of apple will be found in the state, either newly recognized or recently introduced through nursery stock or in other ways. However, since flat limb, green crinkle and mosaic have failed to spread appreciably in California orchards, the elimination of these by care in selection of propagating material should be relatively easy. Indeed this process is already well under way with the first named.

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[5] Professor Cation has kindly shown kodachrome slides of the Hyslop fruits to the writer.

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